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USDA-ARS METEOROLOGICAL MONITORING IN NORTHEASTERN OREGON

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Abstract

In order to collect accurate and reliable meteorological data for research purposes, a well-designed monitoring plan must be implemented. The Agricultural Research Service Columbia Plateau Conservation Research Center (ARS-CPCRC) meteorological monitoring network was designed and developed in order to provide researchers access to high-quality weather data in a "near-real-time" platform. The system was designed such that, in the future, the general public will also be able to access this data in near real time via the internet.

The design and implementation of an accurate and standardized meteorological station for research data collection was a key element in the development of the ARS-CPCRC monitoring network. Each research location provides unique topography, slope orientation, agricultural practices, influenced by microclimates that need to be measured at points representative of the overall research area.

The design, installation, operation, and cost of a representative station in the ARS-CPCRC meteorological monitoring are described.

Key Words
Climate, data acquisition, meteorology, meteorological calibration, real-time data, weather data

Introduction

The ARS-CPCRC at Pendleton, Oregon needs to collect accurate meteorological data. These data are used in creating and verifying mathematical models, determining water use efficiency, studying climatic effects on soil erosion, and studying plant stress associated with developing sustainable soil and water conservation systems. Additionally, the short-term and long-term effects of weather patterns can significantly impact crop yields, and land-use decisions. In order to support these research goals, and to assist in developing a better understanding of local weather patterns, a meteorological monitoring network has been developed.

System Design

The ARS-CPCRC meteorological monitoring network consists of four remote weather stations continuously collecting meteorological data for use in ARS research projects. The stations are located on cooperator properties near Pendleton, Oregon. Figure 1 provides a map indicating the location of each station in the ARS monitoring network.

Although located less than 20 miles apart, each site is necessary due to the rapidly changing weather patterns in this area. The influence of the Blue Mountains to the south and east induce dramatic changes in temperature and precipitation due to upslope/downslope winds and orographic lifting.

The goal of the monitoring program is to provide a uniform (standard) monitoring station design that incorporates identical sensors and measurement techniques, and allows direct comparison data collected at different locations. Each station collects additional site-specific parameters guided by the research objectives for the project.

A description of the physical location of each site is provided below. Included are the geographic coordinates and the elevation of the monitoring station. The four stations described in this report are as follows:

Duff Site – Located on land farmed by Duff Ranches. Abbreviated as **DNEW**, located in the Wildhorse drainage just north of Oregon Highway 11, Helix Highway. The physical site location is: Latitude - 45° 43.4’ North, Longitude - 118° 39.5’ West, and Elevation: 428.0 m above sea level (asl).

Lorenzen Site – Located on land farmed by Mr. Bill Lorenzen. Abbreviated as **LOR** located in the upper reaches of Little Greasewood Creek, approximately 3.5 miles southwest of Helix. The physical site location is Latitude: 45° 48.8’ North, Longitude: 118° 41.3’ West, and elevation 544.6 meters asl.

Reeder Site – Located on land farmed by Mr. Clinton Reeder and Mr. Paul Reeder. Abbreviated as **RDWS**, located at the junction of Helix Highway (Oregon Highway 335) and Athena Highway (Oregon Highway 334), approximately 2 miles south of Helix. The physical site location is Latitude: 45° 49.0’ North, Longitude: 118° 38.6’ West, and elevation: 546.0 m asl.

Reese Site – Located on land farmed by Mr. Leon Reese. Abbreviated as **RPSET**, located off Interstate 84 on Rhode Road, approximately 1.5 miles northwest of the REW interchange (elevator), Exit 198. The physical site location is Latitude: 45° 44.0’ North, Longitude: 119° 03.0’ West, and elevation: 314.0 m asl.

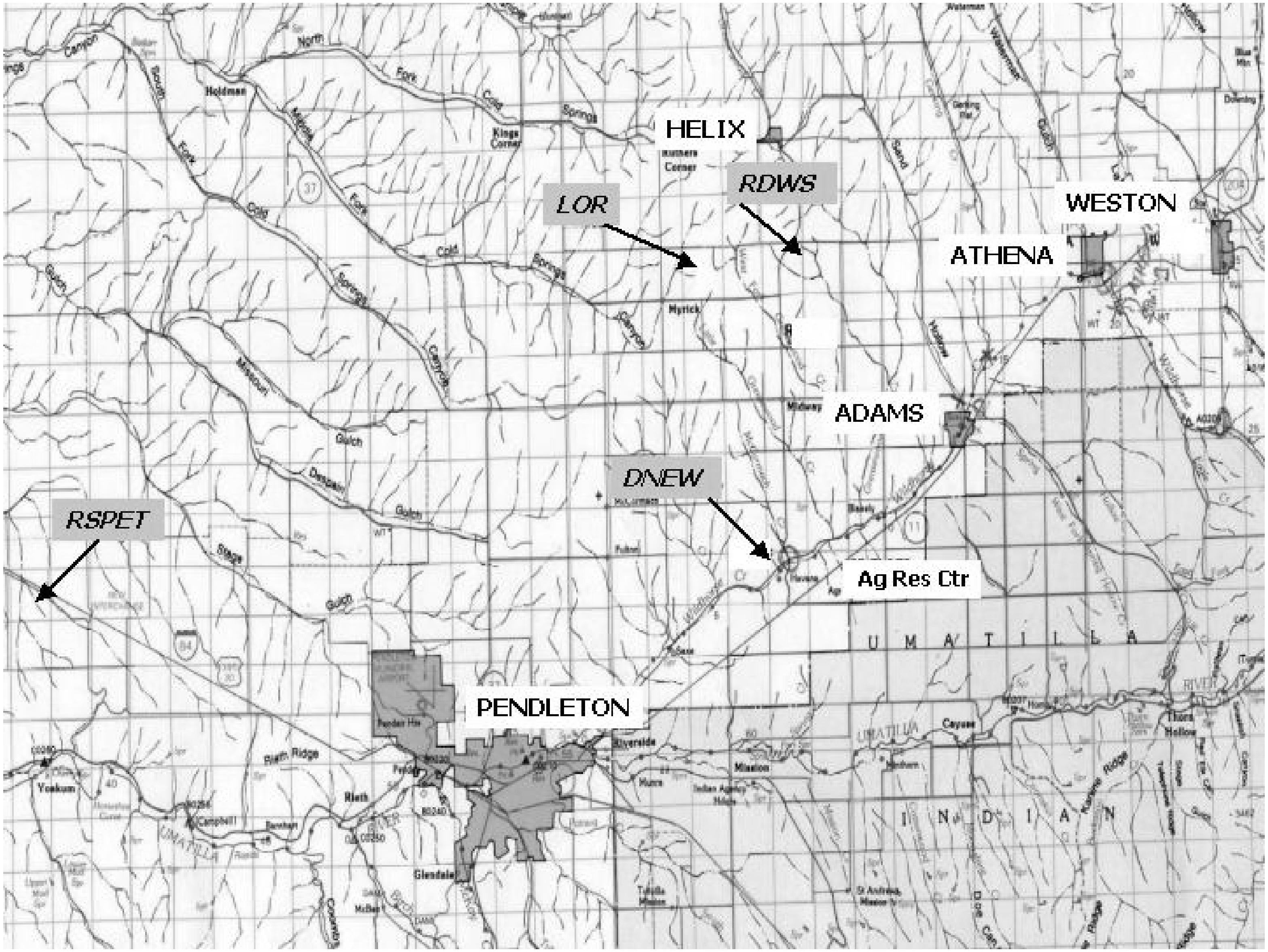

Figure 1. ARS meteorological monitoring network site locations (June 2002).

The monitoring network was designed to use state-of-the-art measurement instrumentation in association with highly reliable data acquisition systems. Through the use of cellular telephone modems, ARS personnel are able to view real-time data, and collect stored data from each station manually or automatically. At a specified time each day, the data are retrieved automatically via computer and cell phone telemetry. Once the data are downloaded, they are screened through the use of a comparative spreadsheet. The spreadsheet evaluates each data point to ascertain consistency with the values immediately before and after. The data are additionally verified and screened manually and visually by an ARS staff member with expertise in meteorological monitoring and data analysis.

Each monitoring site is configured to measure and collect meteorological data representative of the vicinity where research is conducted. The purpose of the measurements is to provide a weather database that can be used to complement the research data collected. The data are then used during the research program, as well as to provide a historical climatic database for that area.

The meteorological parameters measured at each station include; wind speed, wind direction, air temperature, relative humidity, 1 in soil temperature, and 4 in soil temperature, solar radiation, and precipitation. Table 1 provides the information for each parameter measured, including the sensor type, measurement units, component accuracy, manufacturer, and sensor placement in relation to the ground (soil surface).

At certain stations, additional variables are logged and collected depending upon the requirement of the research at the location. The outputs of individual sensors are digitally recorded in the SI units listed in Table 1. The data are stored in hourly averages and daily averages. Hourly and daily averages are derived from an average of each 1-sec scan (3,600 for each hour, and 86,400 for the daily averages). Additionally, daily maximum, daily minimum, and daily totals (where applicable) of parameters are collected and stored. For the maximum and minimum values, the time of occurrence is also recorded for comparative reference between parameters/stations.

Figure 2 shows a photograph of a meteorological station installed at one of the sites and is typical of the stations installed at the other three research locations.

Table 1. ARS meteorological equipment specifications

Variable	Equipment or sensor type	Measurement units	Component accuracy	Sensor Manufacturer[1]	Measurement height (above ground surface)
Digital data acquisition	Analog/digital conversion	Output in engineering units	±0.075% of full-scale range (analog input)	Campbell Scientific, Inc. Model 23X	-
Wind speed	Reed switch anemometer	Meters per second (0-50)	0.25 meters per second or 1.5% of full-scale	Met One, Inc. Model 014A	3 m
Wind direction	Potentiometer wind vane	Degrees (0° - 360°)	±3.0°	Met One, Inc. Model 024A	3 m
Air temperature	Bridge circuit thermistor	Deg C (-40° - +60°)	±0.5°C at -40°C ±0.2°C at +20°C	Vaisala, Inc. Model HMP45C	2 m
Relative humidity	Bridge circuit hygristor	Percent (0-100%)	±3.0% under field conditions (90%-100%)	Vaisala, Inc. Model HMP45C	2 m
1" soil temperature	Bridge circuit thermistor	Deg C (-40° - +60°)	Typically <±0.1°C over -24°C to +48°C range	Campbell Scientific, Inc. Model 107	2.5 cm below soil surface
4" Soil temperature	Bridge circuit thermistor	Deg C (-40° - +60°)	Typically <±0.1°C over -24°C to +48°C range	Campbell Scientific, Inc. Model 107	5 cm below soil surface
Solar radiation	Black and white pyranometer	Langleys per day (0 – 1100)	Absolute error = ±5.0% Max ±3.0% Typical	Eppley Model 8-48 LiCor Model 200X	2 or 2.5 m
Precipitation	Tipping bucket	Totalized rain (inches)	±1.0% up to 10 mm/hr ±5.0% up to 30 mm/hr	Texas Electronics Model TE525	1 m

[1] ARS reference to products, vendors, or manufacturers is for specific information only and does not endorse or recommend that product(s) or company to the exclusion of others that may be suitable.

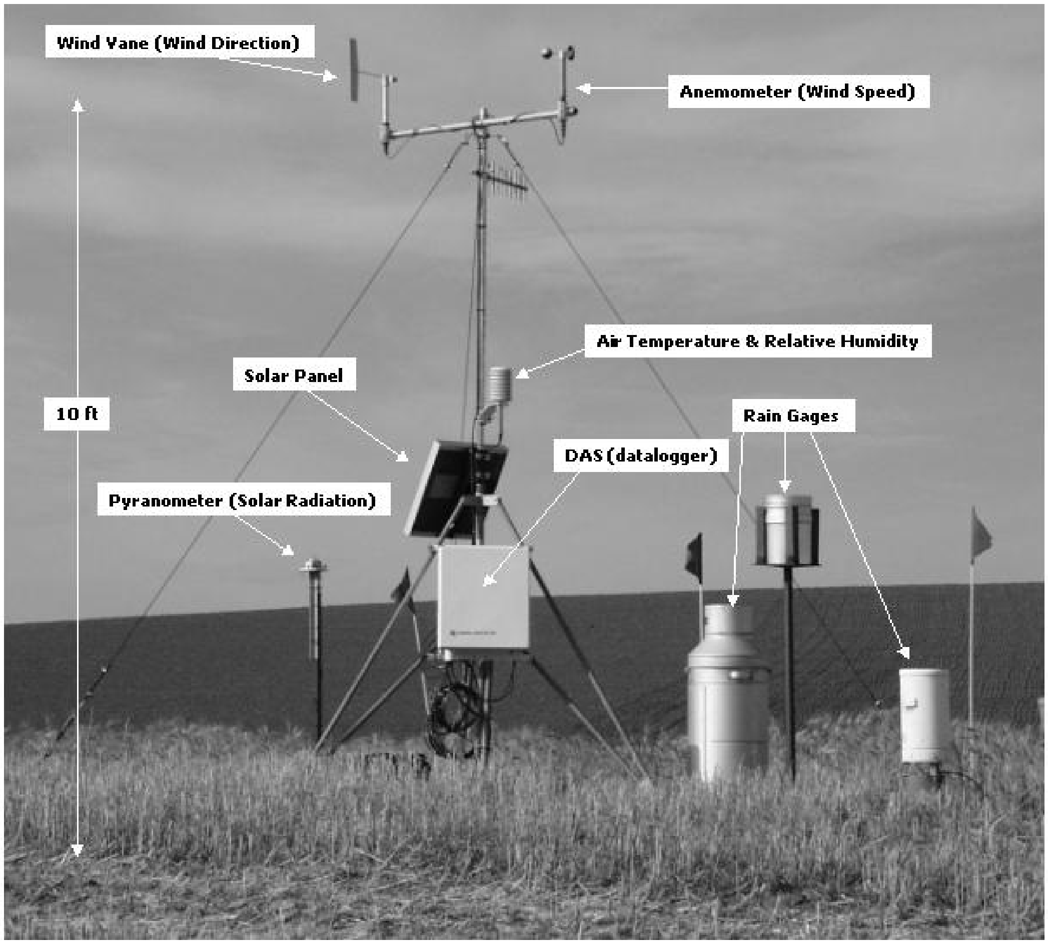

Figure 2. Typical ARS meteorological monitoring installation

Site Selection, Calibration, and Operations

Site Selection

Following is an overview of the tasks required to set-up, implement, install, and operate a station configured with the aforementioned instrumentation. Generalizations have been made in order to provide the reader with a "representative" scheme on the operation of a research-oriented meteorological monitoring station, similar to the ones used at the ARS sites.

Initially, an acceptable location must be selected to conduct the monitoring and collect the measurements. The primary objective is to place the instrument in a location where it can make precise measurements that are representative of the general state of the atmosphere in that area, consistent with the objectives of the data collection program (United States Environmental Protection Agency [EPA] 1989). Issues such as site access, minimization of disruption of local agricultural practices, and site security are also important criteria used for site selection.

The World Meteorological Organization (WMO 1971), National Oceanic and Atmospheric Administration (NOAA 1995), and the U.S. Environmental Protection Agency (EPA 1989), have produced several useful documents and guidelines for the site selection and operation of meteorological systems similar to the ARS systems. The site selection and installation criteria for each of the sensors used are reviewed according to the WMO, NOAA, and EPA guidelines during the system implementation process.

Although ARS does not operate under regulatory guidelines delineated by EPA, the stations in the Umatilla County network are sited, installed, and operated following recommended practices outlined by EPA and other agencies. One major exception is the measurement height of the wind speed and direction sensors. EPA and NOAA recommend a measurement height of 10 m above ground level. The rationale is due to the following: 10 m is the measurement height employed at airports for general aviation. This height is equivalent to the last height that a pilot can take corrective actions on landing and take off. Additionally, EPA requires this measurement height since the data is readily available from most U.S. airports and can be readily used (and scaled up) in air quality dispersion models. The ARS sites measure the wind speed and wind direction at 3 m. This height is used in order to provide measurements more representative of the research activities in the canopy and at ground level.

The ARS network data can be considered of high quality and accuracy, meeting recommended quality assurance guidelines for presentation and acceptance for use in long-term climatological and agronomic studies (Nunes, et.al. 2001).

Once a suitable monitoring site has been identified, documented, and validated, the meteorological station is installed following recommended manufacturer procedures, while meeting the siting and measurement guidelines for meteorological monitoring (NCAR 1984).

The initial phase of system installation consists of wiring and configuration, including the documentation of detailed information regarding sensor type and planned application. The wiring and configuration documentation is vital in the preparation of the site-specific data acquisition software program. The programming effort is driven by the following items: (1) number and type of sensors, (2) power requirements of individual sensors, (3) type of measurement required to achieve final output, and (4) desired data format.

The continuous meteorological data are collected and stored using the programmed Campbell Scientific, Inc. CR23X data acquisition system (DAS). The DAS is equipped with four megabytes of extended memory for on-site data backup (up to 30 days of unattended operation). The data logger contains a nickel cadmium (NiCad) battery backup that provides power for the DAS memory to store date, time, DAS program, and meteorological data, should system power be disconnected, or power outages occur.

Main power for the CR23X is provided by a 12-volt marine battery (80 amp-hour, or equivalent). The battery is continuously charged via a regulated 20-watt solar panel. The CR23X is interfaced to all meteorological sensors by individual shielded signal cables. The on-site cellular telephone and voice modem are also integrated into the system. The data logger and cell phone are housed in a weatherproof NEMA enclosure constructed of heavy-duty fiberglass. The enclosure is mounted on the meteorological tower near the base for easy user access.

Calibration

Initially, operational assessment of individual instruments and sensors is determined at installation/start up and subsequently checked on a semi-annual basis by system and individual sensor calibrations. Additionally, calibrations are performed if sensor maintenance or replacement occurs. The accuracy and reliability of the measurements are determined as the sensors are calibrated against known standards and references. The calibration criteria of the meteorological sensors are defined in Table 2.

Table 2. ARS meteorological calibration methods and tolerance limits

Parameter	Calibration method	Tolerance limit
DAS	Voltage input/output	± 2%
Wind speed	Synchronous motor	≤ 0.1 m/sec
Wind direction	Orientation with respect to true north	± 5º
	Linearity	≤ 3º
Temperature	NIST [1] thermometer collocation comparison	≤ 0.5°C
Relative humidity	NIST psychrometer collocation comparison	± 10%
1 in and 4 in soil temperature	NIST thermometer collocation comparison	≤ 0.5°C
Solar radiation	Certified pyranometer collocation comparison	± 5%
Precipitation	Volumetric addition	± 5%

[1] NIST – National Institute of Standards and Testing .

All calibration equipment is certified by the manufacturer, or by using an NIST equivalent transfer standard (Lockhart 1985). DAS systems are calibrated by applying known voltages or signals with a NIST-traceable voltage generator and verifying DAS output. Wind speed sensors (anemometers) are calibrated by applying a "synthetic" wind speed through the system and verifying that the system output corresponds to the input value. Wind direction sensors are calibrated by sighting along the wind crossarm with a certified precision compass to assure proper orientation with respect to true north. Wind direction potentiometer linearity values are verified by checking the sensor output at 25 different angular positions (12 clockwise, 13 counterclockwise) at 30° increments throughout the entire range of sensor output (0° to 360°). Air and soil temperature sensors are calibrated by direct comparison of the system output to a certified NIST reference standard thermometer accurate to 0.05°C. A multi-point comparison (ice bath, hot water, cool water, and ambient air) is taken with the precision NIST mercury-in-glass thermometer to verify proper temperature response in all ranges. Relative humidity sensors are calibrated by direct comparison of the system output to a certified NIST reference standard psychrometer equipped with thermometers accurate to 0.05°C. Solar radiation sensors (pyranometers) are calibrated and verified by collocating a certified pyranometer with the site pyranometer for a period of 24 hours and comparing data values. Precipitation gauges are calibrated by adding known volumes of water to the gage and verifying sensor response.

Operations

Primary data downloading is accomplished using a personal computer (PC) located at the ARS-CPCRC office. A telephone modem in the ARS PC is used to connect to the DAS, activate the DAS software, and transfer the data.

As a part of routine station operations, an ARS technician visits the monitoring site approximately once every 2 weeks to evaluate the performance and physical condition of the meteorological system and instrumentation. Extreme weather conditions and wildlife can damage the sensors, so each sensor is carefully examined to see that it is functioning properly and in good working order. All individual site maintenance activities, measurement abnormalities, malfunctions, and repairs are entered and documented on a site-specific checklist. The site checklists provide a historical journal of site visit dates, times, operations, maintenance, adjustments, calibrations, and other technician observations.

Any time data are downloaded, either via cell modem retrieval or during the on-site checks, the data are intensively screened to determine their validity. The general purpose of this screening and validation routine is to generate data for the monitoring program that are valid with respect to being: (1) complete, (2) representative, (3) accurate, and (4) comparable with other stations and historical climatic trends. It is necessary to develop and define criteria for determining valid data for meteorological measurements. ARS has developed a screening spreadsheet to review the data for these criteria. Additionally, an ARS staff member, with an extensive data analysis and verification background, reviews each data set as it is retrieved from the station to further ensure data validity and accuracy. Control limits established for individual parameters are used in the data validation process. Measurements that found to be "out-of-tolerance" are identified during instrument inspection (site checks), and during data screening.

Meteorological parameters are monitored on a continuous basis and averaged and recorded digitally in hourly and daily values. The primary means of data processing is via the digital record and output from the validation and averaging spreadsheet used for generation of the data report. A raw data record is archived. Once the raw data is processed for a specific time period, the visual screening checks are performed. These procedures include:

- Verifying data exist and are properly identified;
- Verifying data are in proper format;
- Verifying data identifiers conform to monitoring time periods;
- Identifying missing or anomalous data.

The initial method of editing the digital data involves the comparison with the upper and lower limits of the allowed range. This screening is conducted using the validation spreadsheet. If values outside the allowed range limit are discovered, they are flagged accordingly and documented for future reference.

The data files are also checked for reasonableness based on expected minimum/maximum ranges for the eastern Umatilla County region (using Pendleton airport NWS site, as well as records from other stations in the network). The data reduction screening spreadsheet is used to properly format and reduce the data file.

In addition to the general screening procedures outlined above, the screening criteria in Table 3 have been incorporated into the ARS data reduction program to assist in the validation portion of the data review.

Once the data sets have been validated and anomalies removed, the data is sorted chronologically. Site specific data required by the various research projects are evaluated by the lead researcher(s). All data are archived on a monthly basis for future reference. Only complete, verified, and validated data are incorporated into the final archived database. These data sets are available for use by the general public or other research agencies.

Table 3. ARS meteorological data screening criteria

Variable	Screening criteria (flag data for review if:)
Wind speed	1. Is threshold <0.5 m/sec; or >35 m/sec 2. Does not vary by >0.2 m/sec for 3 consecutive hours 3. Does not vary by >0.5 m/sec for 12 consecutive hours
Wind direction	1. Is <0° or >360° 2. Does not vary by >1° for >3 consecutive hours 3. Does not vary by >10° for 18 consecutive hours
Temperature	1. Is > record high (monthly) for E. Umatilla County Region 2. Is < record low (monthly) for E. Umatilla County Region 3. Is >5°C change from the previous hour 4. Does not vary by more than 0.5°C for 12 consecutive hours
Relative humidity	1. Is >100% or less 0% 2. Is >25% change from the previous hour 3. Does not vary >5% for 12 consecutive hours
1 in and 4 in soil temperature	1. Is value > or < air temperature 2. Does not vary by>0.5°C for 4 consecutive hours
Solar radiation	1. Is value <0, or > than average daily value (month) 2. Does not vary diurnally
Solar Radiation	1. Is value < 0, or > than average daily value (month) 2. Does not vary diurnally
Precipitation	1. Is hourly or daily value <0, or >10 mm 2. Is Daily value >25 mm 3. Daily value exceeds max value for daily accumulation in E. Oregon

Cost

Table 4 provides a brief description of the equipment used at each station, with an associated cost. This information is provided in order to give the reader a general idea of the capital requirements necessary to implement and conduct meteorological monitoring. The total estimated system cost of $10,000 would provide an end-user with a system capable of collecting weather data in user-specified time intervals. Additionally, the quoted system will allow for real-time data access and remote downloading through the cellular telephone voice modem and dedicated PC. The estimate does not include labor for installation, land lease charges, site access, or easement. The equipment costs presented are for equipment that is identical to that used in the ARS monitoring network. A user could design his or her system (to meet budgetary and measurement requirements) by adding/removing, or replacing components with different instrumentation, which could raise or lower the overall system cost.

Table 4. ARS meteorological system equipment costs.

Variable	Manufacturer	Cost
Digital data acquisition	Campbell Scientific, Inc. [1] Model 23X (incl. Telemetry)	$5,500
Wind Speed	Met One, Inc. Model 014A (incl. Cable)	$400
Wind direction	Met One, Inc. Model 024A (incl. Cable)	$520
Air temperature	Vaisala, Inc. Model HMP45C (incl. cable)	$750
Relative humidity	Vaisala, Inc. Model HMP45C (incl. Cable)	Cost included w/ air temp
1 in soil temperature	Campbell Scientific, Inc. Model 107 (incl. Cable)	$90
4 in soil temperature	Campbell Scientific, Inc. Model 107 (incl. Cable)	$90
Solar radiation	Eppley Model 8-48 LiCor Model 200X	$400
Precipitation	Texas Electronics Model TE525	$400
Equipment tripod	Campbell Scientific, Inc. CM10	$400
Battery and 20 watt solar panel	Campbell Scientific, Inc. Model MSX20R	$650
Data logger Software	Campbell Scientific, Inc. Model PC208W	$400
EQUIPMENT TOTALS		**$10,000** [2]

1 The reference to products, vendors, or manufacturers is for specific information only and (ARS) does not endorse or recommend that product(s) or company to the exclusion of others that may be suitable.

2 This is a total estimated cost based upon purchases made by ARS during 2001 and does not necessarily reflect what an agency or individual would be required to pay if purchasing the equivalent in 2002.

Summary

A monitoring system was designed by the ARS-CPCRC staff in Pendleton, Oregon to provide for the collection of site-specific agricultural research-oriented meteorological data that are accurate and complete at remote locations. The systems employ a variety of accurate and reliable instrumentation linked to user-friendly data acquisition systems that can be easily accessed by the researchers. The information can be accessed and retrieved in a real-time platform, which facilitates efficient research analysis and planning.

Extensive programmatic and manual validation is conducted on the collected data sets to ensure that all archived data are accurate.

Currently the ARS-CPCRC meteorological monitoring network is operating at four remote stations. In the future, additional research sites may be established at different locations and additional stations will probably need to be installed. Future stations will be implemented with similar instrumentation and software in order to provide consistency and continuity throughout the network.

Additionally, there are plans, dependent upon funding, to provide access to the data via an internet-based platform (web page or ftp site), to members of the general public, growers, or other agencies interested in meteorological data. At this time, interested parties are welcome to contact the authors to access or obtain data from any stations in the monitoring network. It is important to note that the network has been installed, implemented and brought into operational status between June 1, 2000, and September 1, 2000.

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